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Title: LUNA Condition Based Monitoring Update: Reducing the number of Sensors for Excess Load and External Leak

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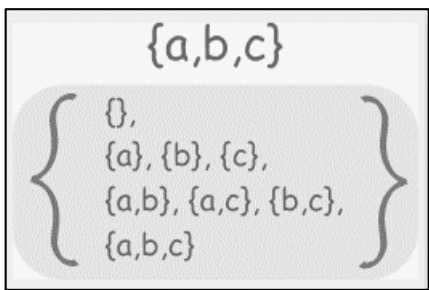
LUNA Condition Based Monitoring Update:
Reducing the number of Sensors for Excess
Load and External Leak

Presented 5/18/2021

Eleak & Eload | Reducing the Number of Sensors

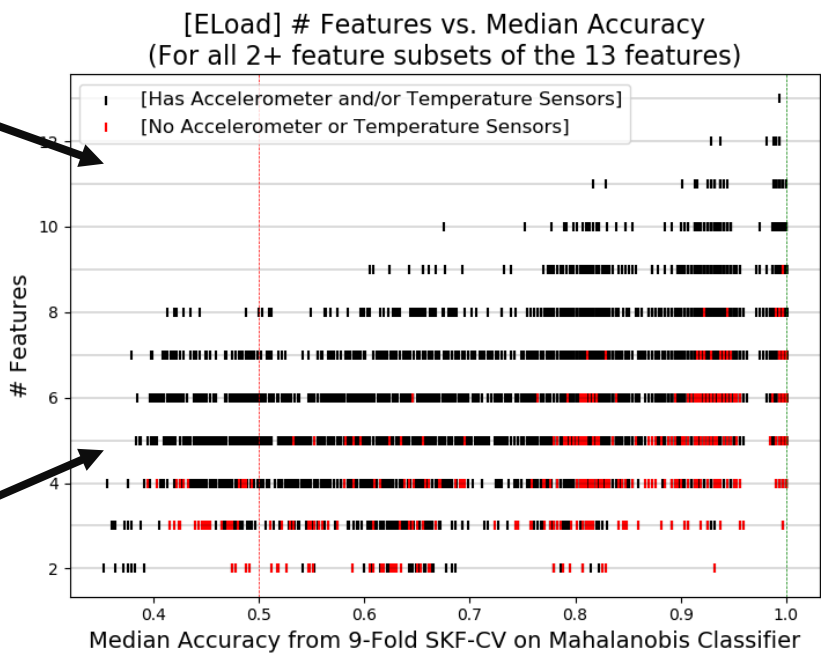
All Usable Subsets of the Set of Features

(For 13 features, there are ~8,192 [2^{13}] subsets)

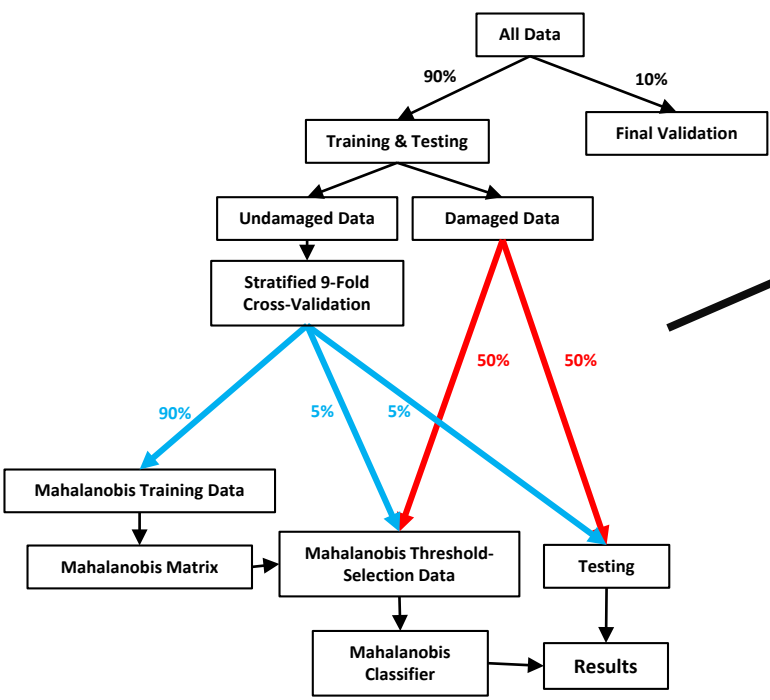


Median Performance of Each Feature Subset

of Features vs. Median Accuracy



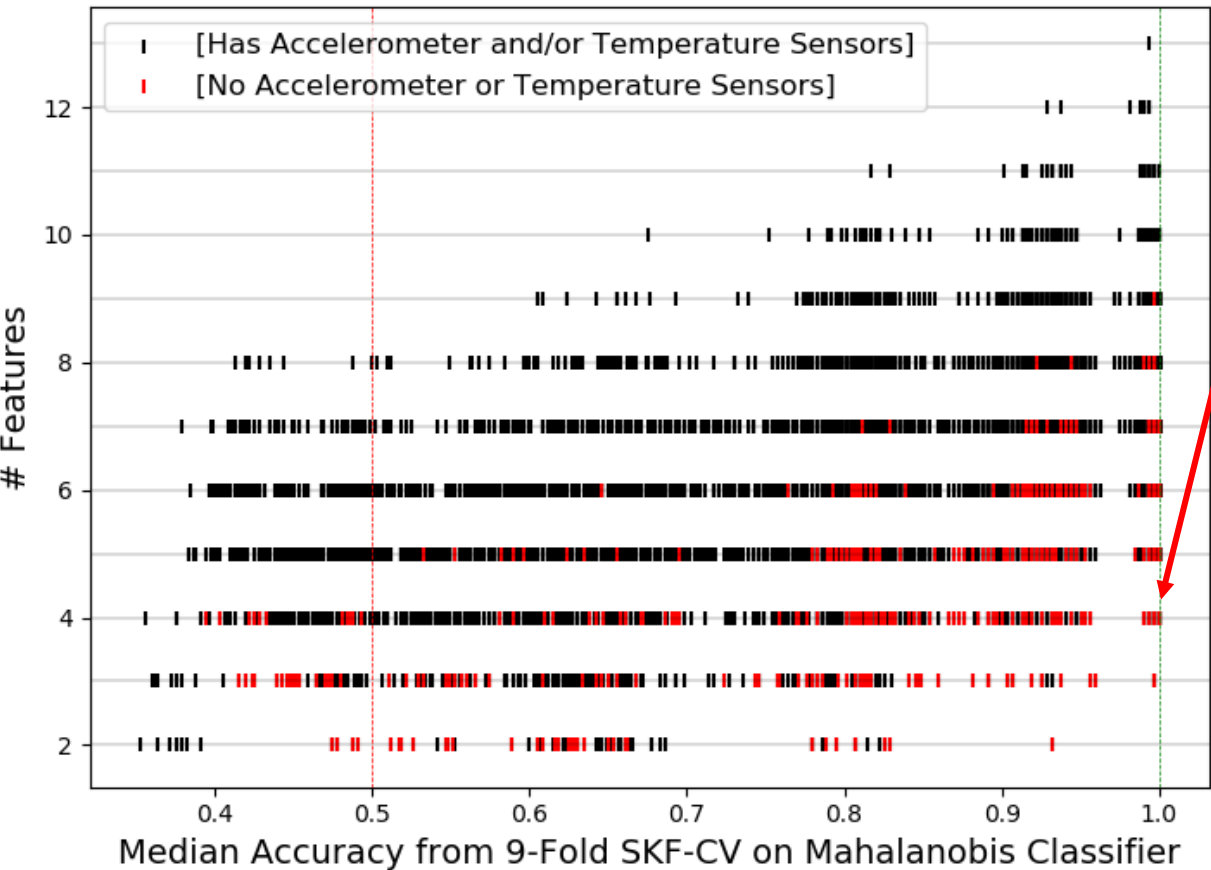
Mahalanobis Classifier Construction & Testing Process



Each point on the scatterplot represents the median accuracy from the 9 classifiers generated during the 9-fold stratified cross-validation.

Eload | # Features & Median Accuracy

[Eload] # Features vs. Median Accuracy
(For all 2+ feature subsets of the 13 features)



Red points indicate feature sets which omit accelerometer and temperature sensors. There are several high-performance feature sets for Eload which do not require these sensors.

This slides' graphs and numbers use Eload 000, 300, 375, 480, and 650 as undamaged, and Eload 1200, 1400, 1500, and 1600 as damaged. The 0, 28K, 50K, 75K, 100K, 125K, 150K, 175K and 200K actuation datasets were used.

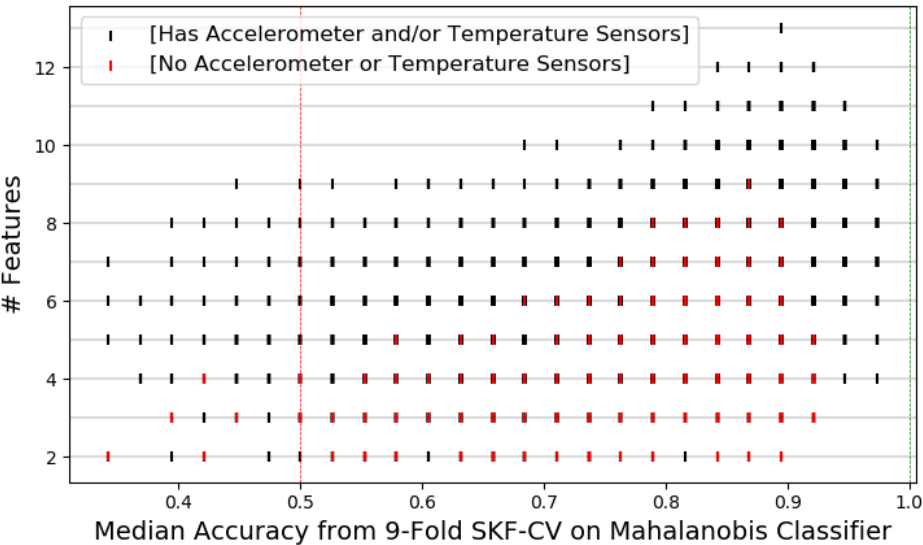
100% Median Accuracy
Small Feature Subsets
[Eload 0-650 considered undamaged, >=1200 damaged]

- [3, 4, 6, 7]
- [6, 7, 9, 10]
- [4, 6, 7, 12]
- [6, 7, 9, 12]

- Feature Key**
- 0: 'Var_of_Accel_1',
 - 1: 'Var_of_Accel_2',
 - 2: 'Var_of_Accel_3',
 - 3: 'Mean_of_PG_1',
 - 4: 'Mean_of_PG_2',
 - 5: 'Mean_of_PG_3',
 - 6: 'Var_of_PG_1',
 - 7: 'Var_of_PG_2',
 - 8: 'Var_of_PG_3',
 - 9: 'Slope_of_Angle',
 - 10: 'Pressure_Diff_Sum',
 - 11: 'Diff_Temp_Var',
 - 12: 'Pressure_Max'

ELeak | # Features & Median Accuracy

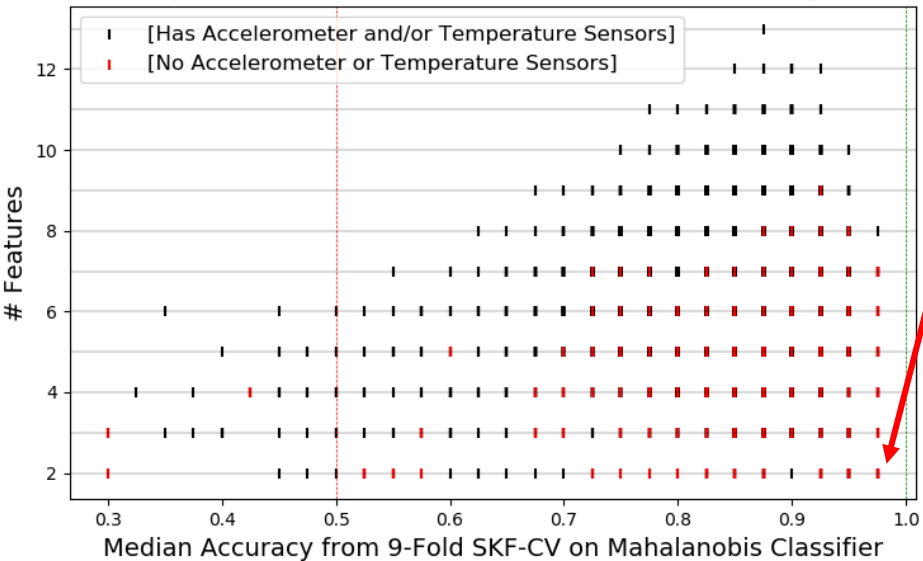
[ELeak Rot. A] # Features vs. Median Accuracy
(For all 2+ feature subsets of the 13 features)



For the difficult rotation (rotation A), accelerometer and/or temperature data is required to get above approximately 93%.

For the easier rotation case (Rot B, angle < median), there are several feature subsets which give 97.5% accuracy on the tested data, using ELeak 005, 010, 020 and 050 as 'undamaged' and ELeak 100 & 150 as 'damaged'.

[ELeak Rot. B] # Features vs. Median Accuracy
(For all 2+ feature subsets of the 13 features)



Rot. B 97.5% Median Accuracy

Small Feature Subsets

[ELeak 0-50 considered undamaged, >=100 damaged]

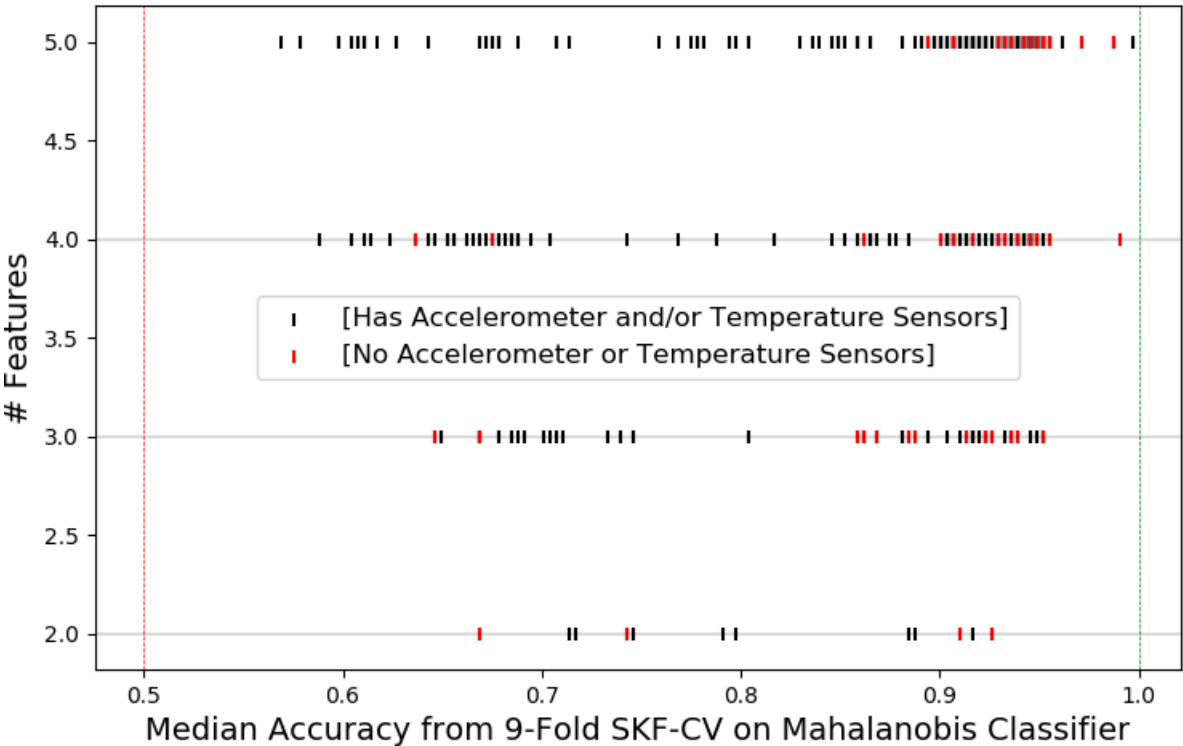
[6, 7] 0.975
[4, 12] 0.975
[6, 12] 0.975
[7, 12] 0.975
[3, 7, 12] 0.975
[3, 4, 7, 12] 0.975
[3, 6, 7, 12] 0.975
[4, 6, 7, 12] 0.975
[10, 12] 0.975
[3, 10, 12] 0.975
[3, 7, 10, 12] 0.975

Feature Key

- 0: 'Var_of_Accel_1',
- 1: 'Var_of_Accel_2',
- 2: 'Var_of_Accel_3',
- 3: 'Mean_of_PG_1',
- 4: 'Mean_of_PG_2',
- 5: 'Mean_of_PG_3',
- 6: 'Var_of_PG_1',
- 7: 'Var_of_PG_2',
- 8: 'Var_of_PG_3',
- 9: 'Slope_of_Angle',
- 10: 'Pressure_Diff_Sum',
- 11: 'Diff_Temp_Var',
- 12: 'Pressure_Max'

Eleak Rot. B vs. ELoad | # Features & Median Accuracy

[ELEak vs. ELoad] # Features vs. Median Accuracy
(For all 2+ feature subsets of the 13 features)



The above graph shows the median performance of each subset for separating Eload from Eleak (rotation B), using only subsets of 2-5 features and dropping ½ of the possible subsets to make computation faster. The full calculation (over all usable subsets) is currently running.

99% Median Accuracy

Small Feature Subset

Discerning Eload (any severity) from Eleak Rotation B (any severity)

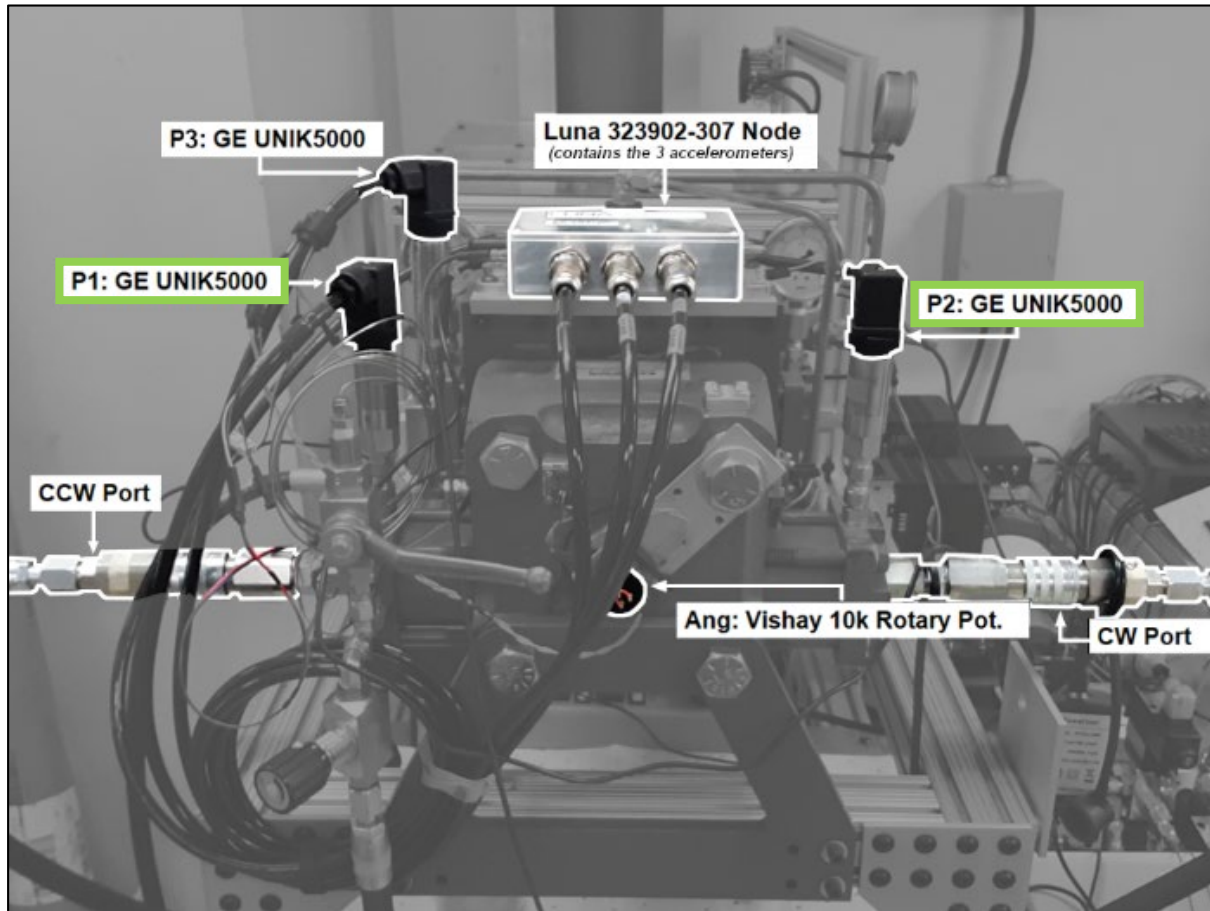
[4, 6, 10, 12], 0.99

All of the features in this subset are derived solely from pressure gauges 1 and 2.

Feature Key

- 0: 'Var_of_Accel_1',
- 1: 'Var_of_Accel_2',
- 2: 'Var_of_Accel_3',
- 3: 'Mean_of_PG_1',
- 4: 'Mean_of_PG_2',
- 5: 'Mean_of_PG_3',
- 6: 'Var_of_PG_1',
- 7: 'Var_of_PG_2',
- 8: 'Var_of_PG_3',
- 9: 'Slope_of_Angle',
- 10: 'Pressure_Diff_Sum',
- 11: 'Diff_Temp_Var',
- 12: 'Pressure_Max'

Eleak & Eload | Reducing the Number of Sensors



*For Eload and one of Eleak's rotation directions, **>97%** accuracy can be achieved (contingent on the threshold considered 'damaged') with just pressure gauges 1 and 2 (highlighted in green), if the type of damage is known.*

Binary Classification Accuracy (Damaged/Undamaged)

Eload

[3, 4, 6, 7] -> **100%** Median accuracy
[PG1 mean, PG2 mean, PG1 variance, PG2 variance]

Eload \leq 650: Undamaged
Eload \geq 1200: Damaged

Eleak (Rotation B)

[6, 7] -> **97.5%** Median accuracy
[PG1 variance, PG2 variance]

Eleak \leq 050: Undamaged
Eleak \geq 100: Damaged

Mahalanobis Convex-Hull Classifier

